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RESEARCH TRENDS IN TURBINE AERODYNAMICS

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ABSTRACT

This paper summarizes the nature of some of the recent trends in turbine aerodynamics research. Areas discussed include cooled turbine aerodynamics, high work-factor turbines, pneumatic variable geometry, and computer analyses.

INTRODUCTION

Turbine aerodynamics research is being directed primarily towards those areas that make the turbine and the engine smaller in size and lighter in weight. Several of these areas form the basis of this discussion:

(1) Cooled turbine aerodynamics - Specific thrust can be increased, with a consequent decrease in engine diameter, by increasing turbine inlet temperature. Higher inlet temperatures require increasing amounts of blade-coolant air. Research is necessary if the turbine is to accept, without severe degradation in aerodynamic performance, the larger blade-coolant flows.

(2) High work-factor turbines - Another research area is associated with the desire for lower fuel consumption and lower noise. These requirements result in higher bypass-ratio engines, with many turbine stages required to drive the high-flow low-speed fan. This research is aimed at increasing the stage work output so as to reduce the number of stages without severe degradation in performance.

(3) Pneumatic variable geometry - If an engine is to perform efficiently over its range of operating conditions, variable geometry of some sort is necessary. One possibility is the use of variable turbine stators, but to do this mechanically in the hottest part of the engine is difficult. Since secondary air in the form of blade coolant is often already supplied to turbine vanes, studies are being made to use this air to pneumatically obtain variable flow area.

(4) Computer analyses - As computers become larger and faster, it becomes possible to use more rigorous and complex design and analysis procedures. A continuing effort is being devoted to updating flowpath design, blading design, and performance prediction procedures.

This paper briefly summarizes the nature of the above mentioned turbine aerodynamics research and serves as a basis for the turbine part

of the "Recent Advances in Turbomachinery Research" panel.

COOLED TURBINE AERODYNAMICS

Over the years, turbine inlet temperature has been increasing and will continue to increase (fig. 1) as a result of advancements in materials and cooling technology. Advanced cooling technology involves injection of secondary air into the main stream by such means as trailing-edge ejection slots, local-coverage film holes, full-coverage film holes, and transpiration surfaces. Each of these cooling methods affects the boundary layer differently, as indicated by figure 2. Blade-row performance, then, becomes a function of such aspects as coolant velocity (fig. 3), injection location, injection angle, and coolant temperature.

Research is being carried out to gain an understanding of the manner in which the various factors affect performance. The variables are being explored systematically in two-dimensional cascades and full-annulus cascades. Many of the configurations are also being tested in cold turbine rigs and hot engine rigs.

Also being worked on are analytical models to predict the aerodynamic performance of various types of cooled blades. Successful prediction techniques, as indicated by figure 4 for trailing-edge ejection, have been developed for some of the cooling schemes.

HIGH WORK-FACTOR TURBINES

As higher bypass ratios are used in engines, the work required from the fan-drive turbine increases rapidly. Stage efficiency, as seen from figure 5, falls off with increasing stage work factor, and the number of stages must increase in order to regain the lost performance. Research is currently directed at trying to reduce the degradation in efficiency at higher work factors and allow a reduction in number of stages needed. Several turbines, including the one shown in figure 6, having high levels of work factor are being tested.

Concepts being studied to achieve the higher work factors include the use of nonfree-vortex design techniques and the use of advanced blading such as tandem airfoils. Figure 7 illustrates the area where the aerodynamic problems are most severe. The tandem blade (fig. 8) obtains high diffusion without separation by allowing the thickening boundary layer to break at the rear of the front foil and start anew on the rear foil.

PNEUMATIC VARIABLE GEOMETRY

During operation of jet-flap blading with the jet off, the exit flow, as with plain blading, is more or less in the direction of the blade exit

angle. With the jet on, as indicated by figure 9, the exit flow turns more toward the tangential direction and the area normal to the flow has decreased. This smaller flow area results in a decrease in primary flow. As indicated by figure 10, after the use of an initial small amount of jet flow that was required to reattach a separated flow in this case, additional small amounts of jet flow caused significantly larger decreases in primary flow. This phenomenon offers the potential for pneumatically induced variable geometry and is being studied for such.

COMPUTER ANALYSES

To properly analyze and design turbines, it is necessary to be able to predict the behavior of the flow in the turbine. Only then can the flowpath profile, blade angles, blade profiles, and design and off-design performance be accurately determined. Programs to perform these tasks (fig. 11) have become available, and in improving versions, during the last decade. As computer capabilities increased, computing procedures advanced from one-dimensional meanline to two-dimensional streamline to quasi-three-dimensional (combining of two-dimensional solutions) techniques.

In order to insure good performance from highly loaded blading, it is necessary to determine and control the flow distribution throughout the blading flow passage (fig. 12). This involves flow solutions in various planes and flow regimes. Two basic computation techniques are primarily used: a velocity gradient method, which is good only for the guided part of the passage, and a stream function method, which gives results for the entire passage. Both of these methods have been used to provide solutions in the meridional, blade-to-blade and orthogonal planes of blade passages.

CONCLUDING REMARKS

In recent years, turbine aerodynamics research has primarily been directed toward allowing the turbine to efficiently accept higher inlet temperature and blade loading. This is being accomplished by such means as studying the interaction between coolant and primary flows so as to be able to obtain maximum cooling with minimum aerodynamic loss, studying the use of advanced blading concepts designed to efficiently increase stage work output, and improving computerized design techniques to yield more complete flow analyses and thus allow the designer to avoid aerodynamic problem areas. The discussion in this paper has covered primarily the above areas.

There are still additional gains to be made by further work in these areas. In addition, other areas requiring study include (1) unsteady flow effects and associated stator-rotor interactions, (2) noise generation in the blading, and (3) supersonic flow analyses including shocks. These latter areas are expected to receive increased emphasis in the future.

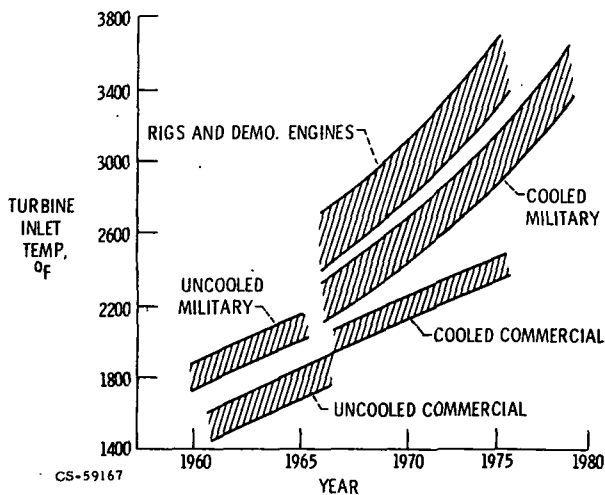


Figure 1. - Trends in turbine gas temperature.

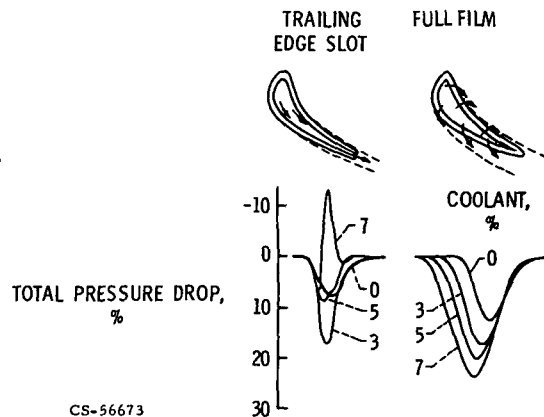


Figure 2. - Effect of cooling method on stator wake traces.

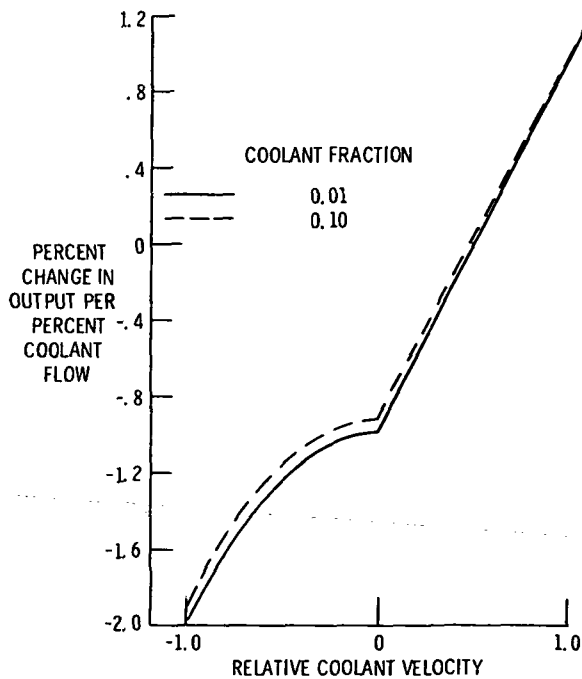


Figure 3. - Effect of coolant velocity on blade row performance.

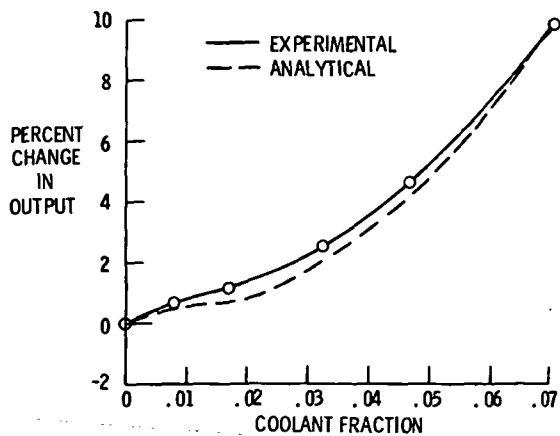


Figure 4. - Comparison of experimental and analytical performance of stator blading with trailing-edge coolant ejection.

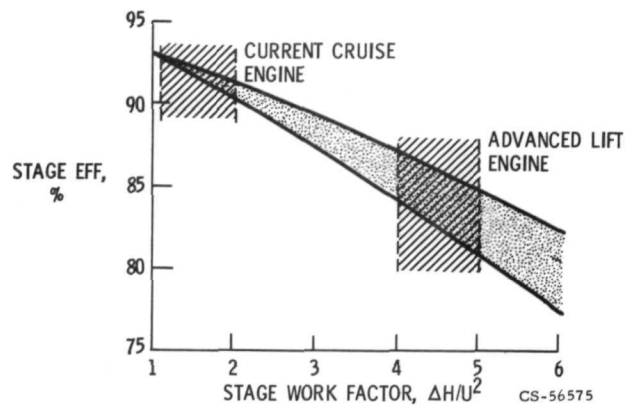


Figure 5. - Effect of turbine stage work on efficiency.

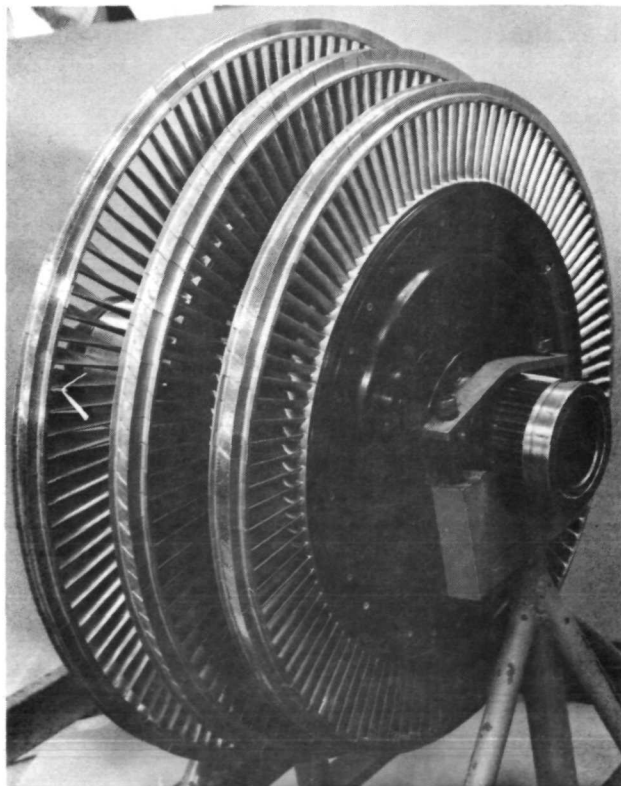


Figure 6. - High work-factor turbine rotor.

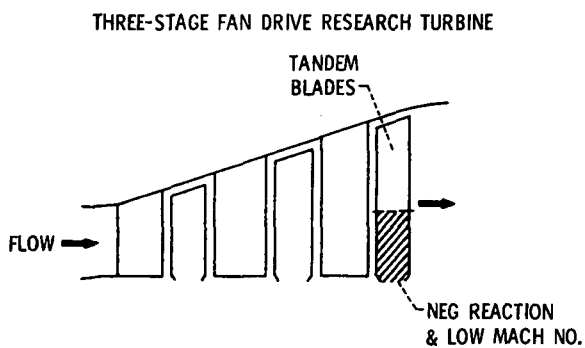


Figure 7. - Application of tandem rotor blades. CS-56672

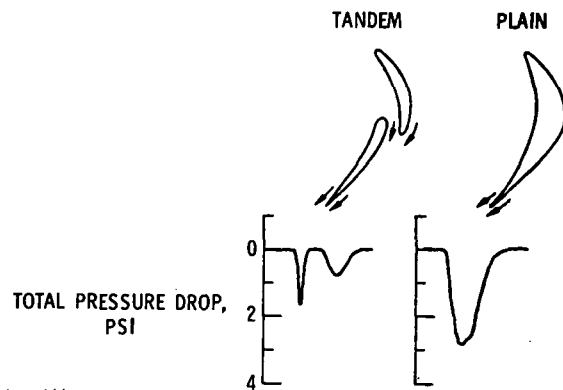


Figure 8. - Wake traces from tandem and plain blades.

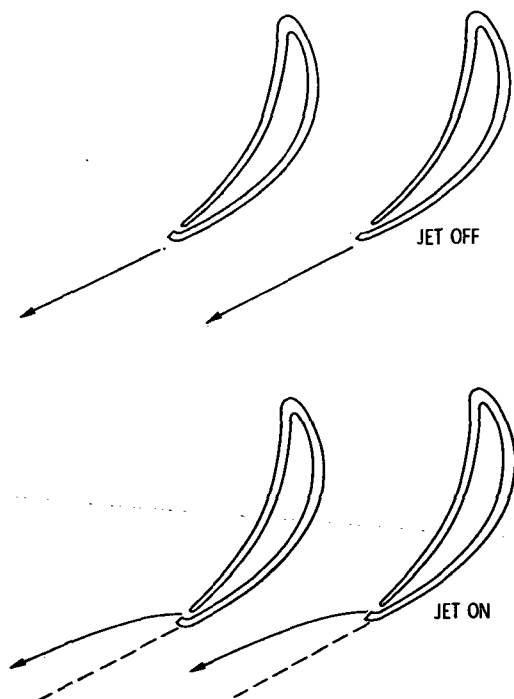


Figure 9. - Pneumatic variable geometry using jet-flap blades.

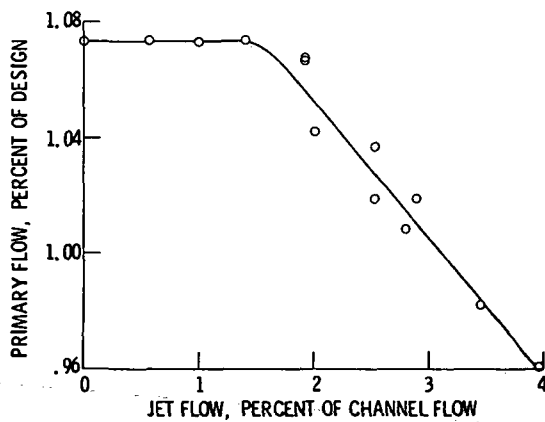


Figure 10. - Primary flow as function of jet flow.

1. DESIGN GEOMETRY AND PERFORMANCE
 - a. RADIAL - MEANLINE
 - b. AXIAL - MEANLINE AND STREAMLINE
2. OFF-DESIGN PERFORMANCE
 - a. RADIAL - MEANLINE
 - b. AXIAL - MEANLINE AND RADIAL SECTOR
3. BLADING BOUNDARY LAYER

COMPRESSIBLE FLOW - LAMINAR AND TURBULENT
4. BLADING FLOW ANALYSIS

AXIAL, RADIAL, OR MIXED COMPRESSIBLE FLOW

TWO AND QUASI-THREE DIMENSIONAL

Figure 11. - Turbine analysis computer programs.

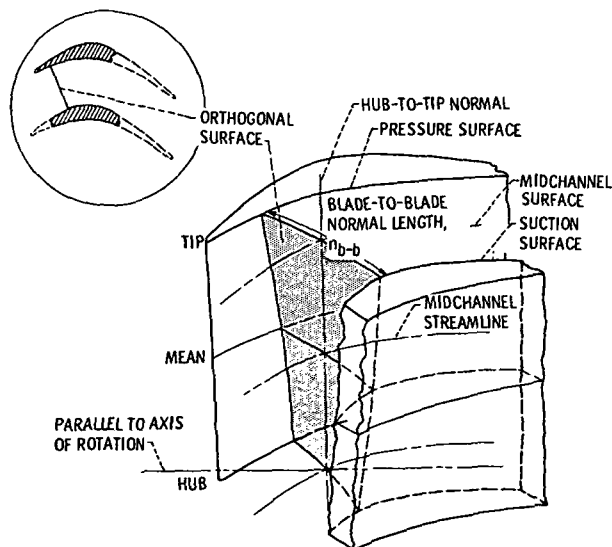


Figure 12. - Pair of typical turbine blades with three-dimensional orthogonal surface across flow passage.